

Tunable Optical Cavities for Gas Sensor



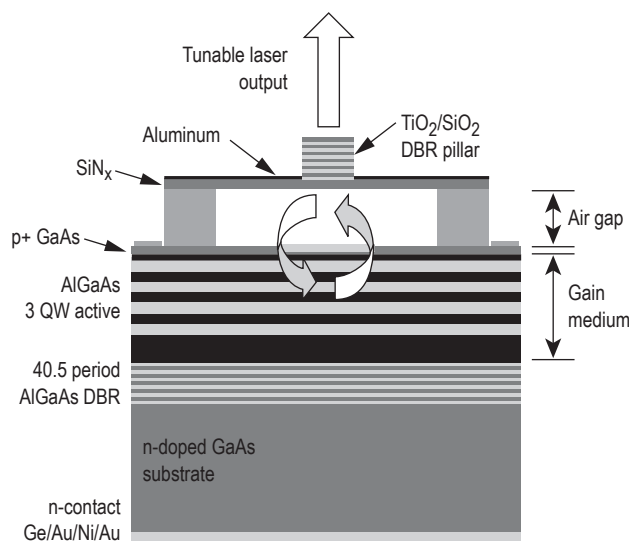
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Trace-gas analysis is critical for real-time environmental monitoring, weapons surveillance, combustion studies, and space exploration. Tunable diode laser absorption spectroscopy (TDLAS) is a powerful approach for in-field IR chemical detection and identification. Recently, MEMS tunable vertical cavity surface emitting lasers (VCSELs) have been implemented for NIR TDLAS. We are exploiting this technology to bridge a capability gap in sensing low weight

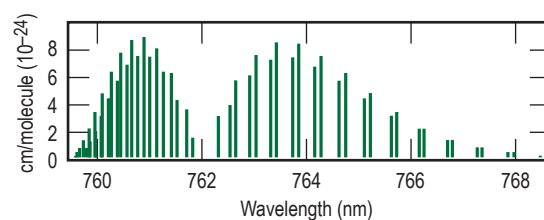
molecules, and to extend it to a miniaturized gas *in-situ* detection platform with built-in multiplexed detection potential. Ground or avionic systems that respectively need unattended, flexible or lightweight, highly sensitive sensors will greatly benefit from this approach.

The technology relies on extended coupled cavity (ECC) MEMS-tunable vertical cavity devices: the epitaxial material is engineered to align the laser emission to a specific absorption wavelength (coarse tuning), and the top suspended mirror causes a continuous scanning across the absorption lines of the gas (fine tuning) when deflected by an applied voltage. The device will be used for standard TDLAS. Ultimately, it can be described as a multipass cell with optical gain (Fig. 1). In operation, the laser is electrically driven above threshold; the gas flowing through the air gap spoils the gain-loss balance necessary for lasing by increasing the absorption losses within the cavity. Absorption is enhanced as the light is reflected several times within the resonant cavity, between the top and bottom distributed Bragg reflectors (DBRs).

Figure 1. Cross-sectional schematic of MEMS tunable ECC-VCSEL for O_2 sensing. The presence of gas in the air gap quenches the laser emission when the resonance wavelength is tuned to correspond with an appropriate absorption line.



(a)



(b)

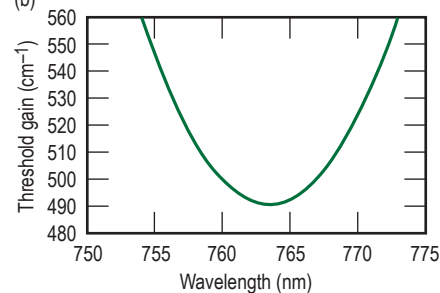


Figure 2. (a) Signature of O_2 at ~ 760 - HITRAN source; (b) modeled laser threshold gain displaying continuous emission tuning for O_2 sensing.

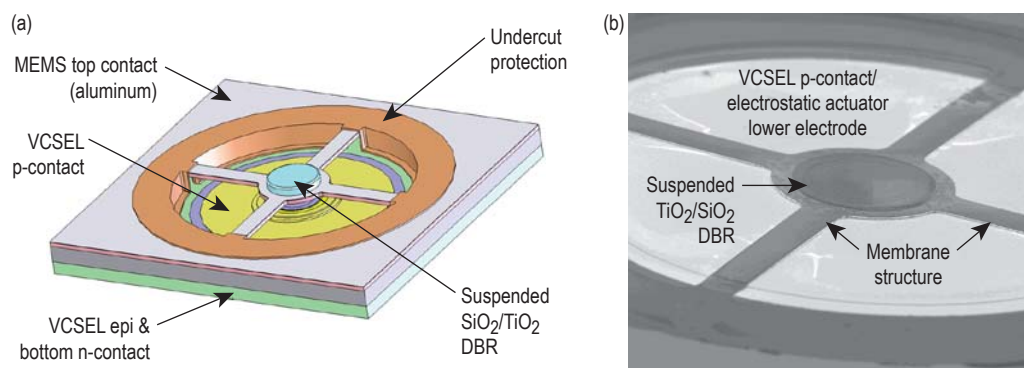


Figure 3. (a) 3-D model of the tunable VCSEL. Note that the scale of the air gap has been exaggerated to clarify the free-standing nature of the micromechanical structure. (b) SEM picture of tunable membrane.

Project Goals

Our goal is to establish complex fabrication procedures to reliably reproduce electrostatically tunable MEMS vertical lasers. The project focuses on reducing them to efficient and miniature gas sensors. Finally, we wish to explore their effectiveness, in selectively detecting the signature absorption lines of the gas of interest, and the limit of detection (LOD) both theoretically and experimentally. We expect to be able to scan with a very narrow linewidth (< 1 pm) the full 10- to 20-nm gas spectrum with actuation voltages < 10 V, and power consumption of a few mWs.

An example of gas spectral signature is given in Fig. 2 (a) for O₂. Some initial estimates of the sensitivity show that LODs of 100s of ppm (for a system level resolution $\Delta P/P = 10^{-3}$) are achievable for gases with cross-sections $\sigma_{\text{NIR}} \sim 10^{-22}$ cm²/molecule.

Relevance to LLNL Mission

Our project supports several applications at the core of LLNL's national security missions, from Stockpile Stewardship to Homeland Security. It will

sustain the generation of a new class of compact, fiber compatible optical gas sensors for real-time detection of chemical agents. This will facilitate minimally invasive trace-gas analysis for next-generation weapons with built-in persistent surveillance; monitoring of in-field explosive detection; nuclear material production activities and environmental pollution; and healthcare. The 2-D nature of the technology enables other interesting applications such as multiplexed smart detection systems, adaptive imaging, beam forming, optical computing, and high power lasers.

FY2007 Accomplishments and Results

In the first year we started, as planned, with a survey of the state-of-the-art technology reported in literature for low-weight molecules detection and investigation of gas species spectral properties. We down selected O₂ for a proof-of-concept at $\lambda = 760$ nm, based on membrane and epilayers requirements and constraints. We have assessed and established the required processes on dummy samples (Fig. 3). We have fabricated 760-nm LEDs on the

epistructure (Fig. 4), which performed well, demonstrating the good quality of the material. We have set up optical and mechanical measurement systems for (tunable) MEMS characterization. Fixed and tunable VCSELs have been fabricated, tested and are going through troubleshooting for optimization.

Related References

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2. Kogel, B., *et al.*, "Micromechanically Widely Tunable VCSEL for Absorption Spectroscopy at Around 1.55," *IEEE MEMS Conference*, MA2, pp. 7-8, 2006.
3. Cole, G. D., E. S. Björlin, Q. Chen, C.-Y. Chan, S. Wu, C. S. Wang, N. C. MacDonald, and J. E. Bowers, "MEMS-Tunable Vertical-Cavity SOAs," *IEEE J. Quantum Elect.*, **41**, pp. 390-407, March 2005.

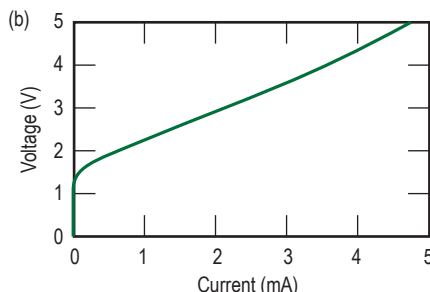


Figure 4. (a) Light emission from LED before completing full VCSEL process; (b) IV curve with the turn on < 2 V.

FY2008 Proposed Work

We will complete the establishment of the enabling capability by fully characterizing the MEMS membrane and tunable VCSELs in terms of reflectivity, emitted power, spectra, voltage tuning, and power consumption. Preliminary gas testing experiments for O₂ TDLAS at 760 nm will be attempted using existing facilities. The spectral and intensity cross-sensitivity to different gases will also be investigated. We will focus the efforts on gas testing and determination of spectral and amplitude sensitivity of the devices.